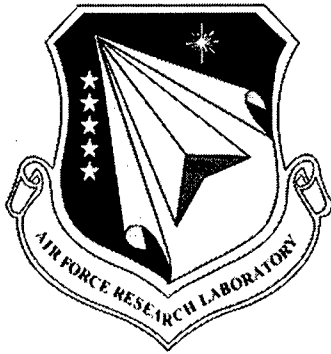


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**Work-Centered Design and
Evaluation of a C2
Visualization Aid**

Emilie Roth

**Roth Cognitive Engineering
89 Rawson Road
Brookline MA 02445**

**Ronald Scott
Tom Kazmierczak**

**BBN Technologies
10 Moulton
Cambridge MA 02115**

Randall Whitaker

**Northrop Grumman Information Technology
2555 University Blvd.
Fairborn OH 45324**

**Mona Stilson
Gina Thomas-Meyers
Jeffrey Wampler**

**Air Force Research Laboratory
Cognitive Systems Branch
Wright-Patterson AFB OH 45433**

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Wright-Patterson AFB OH 45433-7604**

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WORK-CENTERED DESIGN AND EVALUATION OF A C2 VISUALIZATION AID

Emilie Roth†, Mona Stilson§, Ronald Scott‡, Randall Whitaker~,
Tom Kazmierczak‡, Gina Thomas-Meyers§, and Jeffrey Wampler§

† Roth Cognitive Engineering, Brookline, MA

‡ BBN Technologies, Cambridge, MA

~ Northrop Grumman Information Technology, OH

§ Air Force Research Laboratory, Wright-Patterson AFB, OH

Command and Control (C2) operators increasingly need to assimilate large amounts of near-real time data distributed across multiple sources to identify, interpret, and mentally fuse the information necessary to accomplish their work. We have been developing and applying work-centered design and evaluation methodologies to design advanced visualization and support tools intended to more effectively support C2 cognitive and collaborative work. The paper reports the results of a work-centered evaluation assessing the usability and usefulness of an innovative work-centered visualization aid (a graphic mission timeline display) we developed to support mission replanning during execution in a C2 airlift service. The evaluation compared performance with the work-centered visualization to performance using the existing information technology system. The work-centered visualization produced statistically significant improvement in task completion time, errors, workload and situation awareness. The results point to the value of taking a work-centered analysis and design approach.

INTRODUCTION

Command and Control (C2) operators are increasingly faced with the need to assimilate large amounts of near-real time data. Too often the needed information is distributed across a variety of sources requiring operators to find, interpret and mentally fuse disparate data in order to successfully accomplish their work. A challenge for the Cognitive Systems Engineering community is to develop and disseminate more effective methods for addressing cognitive and work-centered issues during C2 system design, development and evaluation.

Over the last several years, we have been developing and applying work-centered design and evaluation methodologies to the design of advanced visualization and support tools intended to support cognitive and collaborative work within a C2 airlift service organization (e.g., Eggleston and Whitaker, 2002; Eggleston, 2003; Eggleston, et al., 2005; Scott, et al., 2005; Wampler, et al., 2005).

Key elements of work-centered design include: (a) An analysis and modeling of the demands of work, (b) the design of displays/visualizations that reveal constraints/affordances coupled with 'direct aiding' support that utilizes 'machine intelligence' to integrate data into meaningful information in the context of the work, and (c) the use of *work-centered evaluations* – evaluations that attempt to probe the ability of the support system to support the work across a representative range of work context and complexities (Eggleston, Roth & Scott, 2003; Roth, et al., 2002). The focus is on evaluating not only the 'usability' of the system (the ease with which one can learn and use it) but also the 'usefulness' (the extent to which it facilitates performance of work) and

'impact' (the extent to which it supports the work goals of the individual, the immediate work group, and the organization).

In this paper we present the results of a recent project illustrating our work-centered approach. The paper reports the results of a work-centered evaluation conducted to assess the usability and usefulness of a prototype visualization aid designed to support mission replanning in a military airlift organization. Wampler et al. (2005) provides a more detailed account of the cognitive analyses and design activities that were conducted in support of the design of this visualization aid.

Overview of the Context of Work

The military airlift organization is an air operations center (AOC) responsible for the scheduling and tracking of airlift and air refueling missions worldwide. Mission planning is a complicated activity that must take into account issues such as matching loads to currently available aircraft, landings in and over-flights of foreign nations, competing airlift demands, airfield constraints, air refueling requirements, and aircrew constraints.

Twenty-four hours prior to a planned mission launch, responsibility for the mission is transferred from mission planners to the Execution Cell that is responsible for handling last minute changes and problems that might arise during mission execution. The existing information technology (IT) systems available in the Execution Cell do not effectively support them in easily understanding the flight plan, assessing the impact of changes on the viability of the flight plan and revising the plan appropriately. Although all the relevant data is available, it is presented in a tabular form that requires

navigation across multiple tabular displays to extract and mentally collate the necessary information. (See Figure 1).

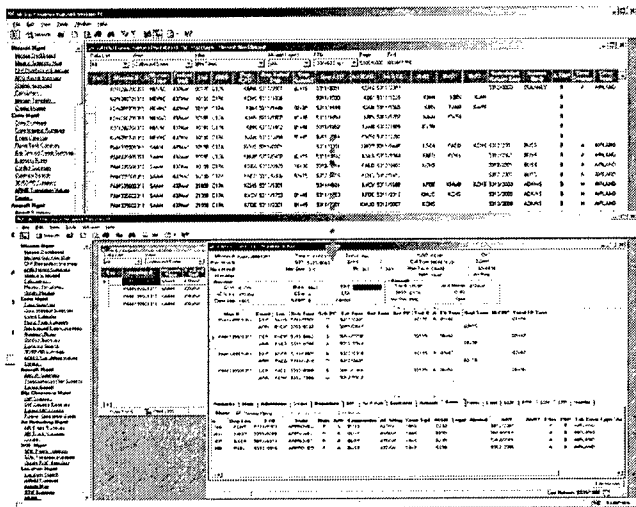


Figure 1. Example of the existing IT system tabular displays.

An analysis of the work domain was conducted based on interviews and observations of mission planners and Execution Cell personnel in their work environment. We documented the 'as is' mission planning and execution process, the factors that complicate planning and execution, and the kinds of miscommunications and errors that can produce mission delays and cancellations. A number of 'leverage points', or opportunities for more effective work-centered support, were identified, including:

- More effectively communicating mission plan objectives, details, and constraints to the personnel overseeing mission execution;
- Alerting users to emerging problems (e.g. delays) that threaten the viability of a mission;
- Facilitating the ability to assess repercussions of mission changes (e.g., delays) on the current and subsequent missions (e.g., reaching an airfield after hours; violating crew rest requirements; violating diplomatic clearance time limits).

These three elements of work-centered support correspond to support for different levels of situation awareness (SA) with respect to mission plans. This includes support for the three levels of SA as defined by Endsley (1995): understanding the elements of a mission plan (Level 1 SA); understanding the current situation with respect to delays and impact on the current sortie (Level 2 SA); and projecting impact on future sorties and future missions (Level 3 SA).

Timeline Prototype

Our proposal for a work-centered innovation was a timeline tool that enables users to visualize the temporal characteristics and constraints of a mission plan. The

objective was to provide visibility into decision factors that impact mission viability so that users can readily assess the impact of changes (e.g., delays) on the viability of the mission. A second, related objective, was to support replan decisions by providing a 'what if' capability that allows users to make changes to the mission plan and directly see the impact.

A timeline prototype was developed that enables Execution Cell personnel to "see at a glance" the relationships between mission plan elements and resource constraints. Alerts are integrated into the visualization to highlight exceptions in work context and guide problem-solving. Highly critical factors (i.e., scheduled departure, legs of a mission, origin and destination, ports, air refueling, etc.) are displayed in a "core" visualization and visually correlated on a timescale. This core is available in both a multi-mission view (see Figure 2) and an individual detailed mission view (See Figure 3). The multi-mission view affords summary SA on the overall workstream and alerts the operator to problems that need further investigation. The detailed mission view contains additional relevant factors organized into "clusters" (i.e., airspace, aircrew, airfield, etc). The core and clusters were derived from the analysis of the intrinsic work structure and mental models utilized in mission execution work.

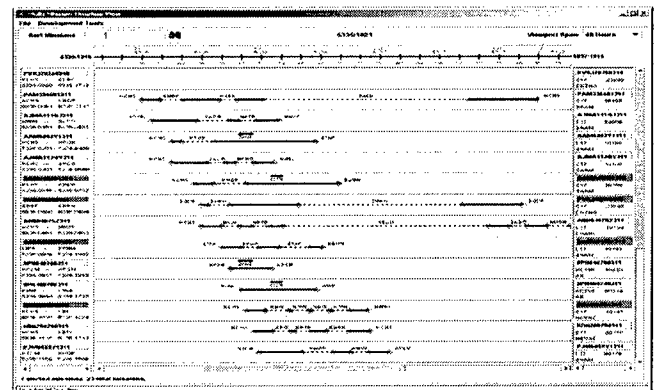


Figure 2. The timeline prototype multi-mission view

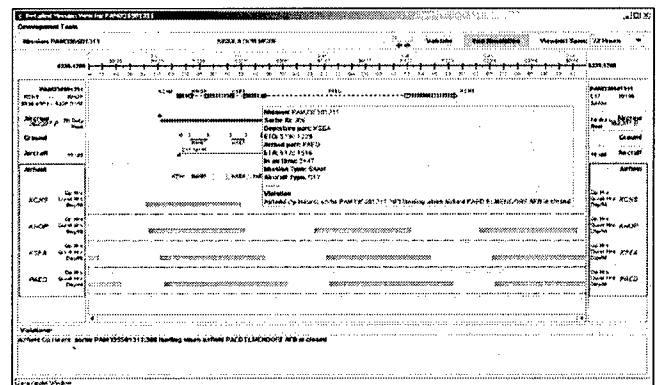


Figure 3. The timeline prototype detailed mission view

An active "what-if" mode is available in the detailed view to help assess alternative courses of action and the future repercussions associated with each alternative. The 'what-if'

mode allows the user to make changes to the mission plan via direct manipulation features. A 'validation' function is provided that checks for resulting constraint violations. Any constraints that are violated will trigger an alert. The user can then make further simulated changes until a workable course of action is found that will lead to a viable plan.

Work-Centered Evaluation

As part of the work-centered development process, we conducted a work-centered evaluation of the timeline prototype. As Woods and his colleagues (1998; Potter, Roth, Woods and Elm, 2000) have argued, new support technologies should be regarded as hypotheses about what constitutes effective support, and how technological change is expected to shape cognition and collaboration (Woods and Dekker, 2002). This is a fundamental premise of the work-centered design framework.

A key objective of a work-centered evaluation is to assess whether the proposed design concepts, as embodied in the prototype, have the positive effects predicted by the system developers (i.e., to evaluate the 'hypothesized model of support'). The specific anticipated benefits of the timeline included:

- A decreased in time to recognize impacts of mission changes during execution;
- A decreased number of errors in replanned missions in execution.

The evaluation tested these hypothesized benefits by comparing performance of Execution Cell personnel using the timeline with performance using their current Information Technology Systems on comparable scenarios.

A second hallmark of a work-centered evaluation is that it includes meaningful measures of performance that tap not only the usability of the system but also the usefulness and impact of the system (Eggleston, Roth and Scott, 2003). Usability, usefulness and impact at different levels within the organization were assessed using a post-test questionnaire.

A third hallmark of a work-centered evaluation approach is that it supports a formative evaluation function as well as a summative evaluation. The work-centered evaluation aims to uncover additional demands and unanticipated requirements at the level of work support so as to propel further work-centered design innovation (Eggleston, Roth and Scott, 2003). This was accomplished via observation of users interacting with the timeline as well as solicitation of user comments and suggestions as part of the post-test questionnaire.

An additional objective of the evaluation was to demonstrate that program success criteria established by the Integrated Product Team (IPT) championing the project were met. Key Performance Parameter (KPP) success criteria to be established by the evaluation were:

- User Acceptance (via post-test questionnaire): 60% participant acceptance established as a minimum requirement, 90% as the objective;

- Improved mission-related SA: Level 2 SA (comprehension of current situation) established as a minimum requirement, Level 3 SA (ability to project impact on future sorties and missions) established as the objective.

METHODS

Design

The study used a within subjects design to compare the performance of Execution Cell personnel using the timeline prototype (timeline condition) against their performance using their current IT system displays (legacy system condition) on each of five comparable scenarios/trials. The order of the two test conditions and scenarios presented were counterbalanced.

Participants

Twelve experienced current, Execution Cell personnel volunteers participated in the study. Participants had a mean of five years experience in their position with a range of .5 to 11 years. While they had all received previous training on the legacy system and were expected to use it to perform their work, the extent of actual use varied due to some preferences for previous versions of the legacy system that were still available for use.

Procedure

Test sessions were conducted in a closed office located close to the operations center for the convenience of the evaluation participants. Each participant was tested individually. A test session lasted approximately 2.5 hours and included:

- Introduction, demographics questionnaire, informed consent.
- Training on timeline: 30 minutes (immediately prior to presentation of timeline condition).
- Two Test conditions
- Post test questionnaire

A fixed database containing a representative set of missions fed both a current IT system client, and the timeline server machine. Test participants used either the legacy system or the prototype timeline (both of which ran on a laptop attached to a desktop monitor) to assess the effects of mission changes on the feasibility of completing a mission as planned.

Test participants saw different, but comparable, realistic work scenarios in the two test conditions. Each test condition consisted of one practice trial followed by 5 test trials. Test scenarios in the trials included violations of port/airfield operating hours; quiet hours; air refueling reservation times; crew duty day; crew return time; and impact on next mission.

Test scenarios consisted of two parts or phases: an 'initial call' specifying a delay in a mission leg, where the test participant was asked to assess repercussions of delay if any, and a 'suggested solution' phase, where they were presented with a possible solution and asked to indicate whether the

suggested solution eliminated problems and/or introduced new problems. Initial call and suggested solution information was presented on index cards.

We recorded the time to assess impacts in both the initial and suggested solution portions of the trial (using a stop watch) as well as errors. Any usability issues in using the timeline prototype were documented.

After each condition, participants filled out a NASA TLX workload rating form (Hart, S. G. and L. E. Staveland 1988), and an SA self report rating form for that test condition. The SA form included likert-rating scale questions for levels 1, 2 and 3 SA as operationally defined for the mission plan domain. At the end of the two test conditions, test participants completed a post-test questionnaire that included Likert-rating scale questions on usability, usefulness, and impact on C2 organization objectives of the timeline prototype. Participants were also given the opportunity to write in comments on the usefulness of the timeline prototype and any suggestions for improvement in the post-test questionnaire.

RESULTS

Statistical analyses were conducted comparing performance on the test scenarios with the timeline with performance using the legacy system.

Task Response Time

Analyses of variance indicated statistically significant differences in response time between the timeline and legacy system conditions for both the initial call (IC) portion ($F=66.29$, $df=1,11$, $p<.0001$) and suggested solution (SS) portion ($F=6.60$, $df=1,11$, $p<.03$) of the test scenarios. The timeline condition led to significantly faster answers in both cases (See Figure 4).

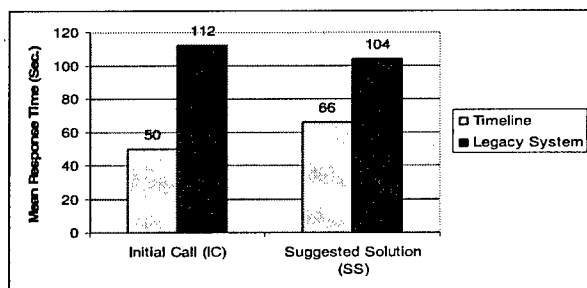


Figure 4. Mean response time to assess repercussions of mission changes with the timeline vs. legacy system.

Errors in Replanning

Participants made fewer errors in the timeline condition (See Figure 5). The differences in error rates were statistically significant on the IC portion of the scenarios (e.g., Chi-square = 10.568, with 1 degree of freedom $P = 0.0012$). While error rates were also lower with the timeline than with legacy system for the SS portion, the results only approached

significance (e.g., Chi-square = 3.01 with 1 degree of freedom $P = 0.0828$).

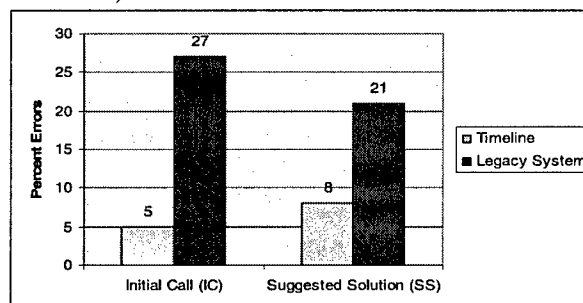


Figure 5. Percent error in answers to test scenario questions with the timeline vs. legacy system

Situation Awareness

Figure 6 presents mean self ratings on various elements of SA. Mean SA ratings were higher for the timeline than for legacy system in all cases. This included elements that tapped Level 3 SA (i.e., impact on future sorties, impact on future missions, and plan changes needed). Analysis of variance indicated that the differences in SA between the timeline and legacy system conditions were statistically significant ($F=54.97$, $df=1,11$, $p<.0001$).

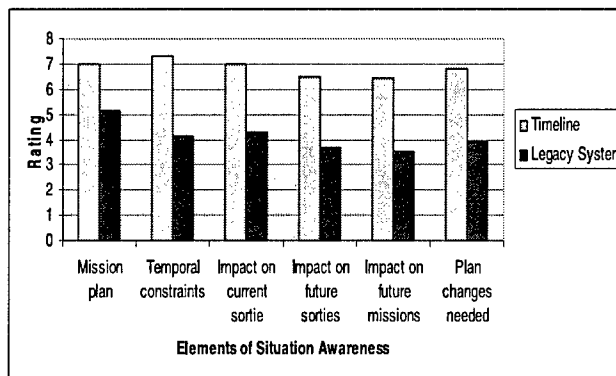


Figure 6. Mean self-rated SA on the various elements of SA for the timeline and legacy system (Scale: 1 to 8; 8 = very high SA).

Workload

Perceived workload, as measured by NASA-TLX, was significantly lower in the timeline condition than in legacy system condition ($F=6.18$, $df=1,11$, $p<.03$). Mean workload ratings are presented in Figure 7.

Acceptance and Impact on Work

The Post test questionnaire ratings were examined to assess test participant perception of the usability, usefulness and impact of the timeline. Mean ratings on all questions were positive (>4 on a 1 to 8 scale, with 1 = extremely negative and 8 = extremely positive). In particular, the question on overall acceptability had a mean of 7.2 and a

range of 6 to 8. Mean ratings were also high for questions relating to impact on own work (7.25); impact on work of immediate work group (7.25); and impact on overall mission of the organization (7.08).

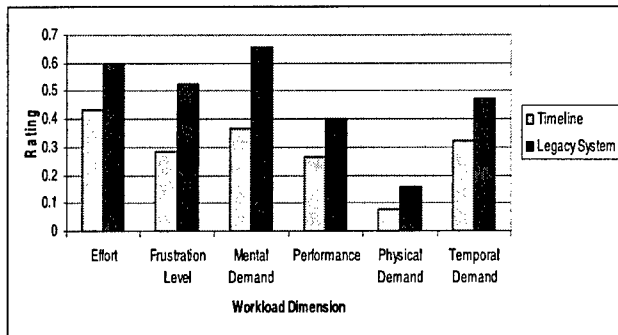


Figure 7. Mean NASA TLX workload ratings. (Scale: 0 to 1; 1= high workload).

Participants also gave the timeline high ratings in response to questions relating to effectiveness of the timeline in decreasing time to recognize impact of changes (7.3); improving ability to generate robust plans (7.2); reducing possibility of replanning error (7) and improving resource utilization (6.5).

Finally, participants' written and oral comments were examined to identify opportunities for improvements to the timeline. A complete list of suggested improvements was documented and reviewed by the design team for inclusion in the prototype deliverables and/or future design activities.

DISCUSSION

The work-centered evaluation established a clear performance improvement with the work-centered timeline visualization as compared with the tabular displays used in the legacy system. Moreover, the results pointed to positive benefits of the timeline prototype with respect to usability, usefulness, and impact on organization mission objectives, as measured by the post-test questionnaire.

The prototype timeline, not only met, but exceeded the performance KPP objectives established by the multi-disciplinary IPT. There are current plans to incorporate the timeline into future upgrades of the operations center IT systems.

The study illustrates the methods and benefits of work-centered design and evaluation. The results point to the value of taking a work-centered analysis and design approach. It highlights the ability of work-centered systems to more effectively support the key cognitive work tasks.

The study contributes to the growing body of literature highlighting the importance of grounding design in a detailed analysis of the context of work (e.g., Vicente, 1999). It illustrates the power of support systems that incorporate visualizations that are finely tuned to the cognitive and collaborative demands of the work, revealing the affordances and constraints in the work domain that impact problem-solving and decision-making (Burns and Hajdukiewicz, 2004).

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